Faculty of Engineering

EFFECT OF STRAIN RATE ON VANE SHEAR TEST

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EFFECT OF STRAIN RATE ON VANE SHEAR TEST

JOHN LING HENG TECK

A dissertation submitted in partial fulfilment

of the requirement for the degree of

Bachelor of Engineering with Honours

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Dedicated To My Beloved Family and Friends.

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ABSTRACT

Investigations on the manipulation of strain rate on saturated clay in vane shear test have been carried out over past 60 years. However, the undrained shear strength of vane shear test on cohesive soil considering the change in excess pore pressure under different strain rate remains unknown. Also, the variation of strain rate of vane shear test depending on the standards considering the pore water measurement is still questionable. Set of procedure was developed to carry out vane shear test with pore pressure measurement to investigate the effect of strain rates of vane on saturated soil to the undrained shear strength of soil and excess pore pressure at different depth. The soil sample is classified as SILT of very high plasticity (MV) based on British Soil Classification System (BSCS) and elastic silt (MH) according to Unified Soil Classification System (USCS). The vane shear test was carried out at the depth of 600mm, 750mm and 900mm, while the strain rate varies from 6, 9, 12, 15, 18, 21 to 24 °/min. From the results, the undrained shear strength from same depth is similar and increases with soil depth. Excess pore pressure is dissipated rapidly at the beginning of the vane insertion, and continued for 6 hours for 600mm soil depth and 3 hours for 750mm and 900mm depth to reach peak value before dropped and stabilized. Excess pore pressure due to insertion and rotation decreases with increasing strain rate. Most difference between the excess pore pressure due to the vane insertion and rotation and excess pore pressure due to the vane insertion at different strain rate is relatively small. The undrained shear strength of the soil increases with the degree of rotation until the peak value before remains constant, meanwhile excess pore pressure rises constantly with time, from 0 to 180 °.

ABSTRAK

Kajian mengenai manipulasi kadar terikan pada tanah liat tepu dengan menggunakan ujian ricih ram telah dijalankan sejak 60 tahun yang lalu. Walau bagaimanapun, ciri-ciri pelbagai jenis tanah dari segi kekuatan ricih taktersalir mempertimbangkan perubahan dalam tekanan liang lebihan di bawah kadar terikan yang berbeza dengan menggunakan ujian ricih ram masih tidak diketahui. Malah, kadar terikan ram bergantung kepada standard mempertimbangkan pengukuran liang air masih terbuka untuk dipersoalkan. Set prosedur telah dibangunkan untuk menjalankan ujian ricih ram dengan pengukuran tekanan liang bagi mengkaji kesan penggunaan kadar terikan ram yang berbeza terhadap tanah tepu dari segi kekuatan ricih taktersalir tanah dan tekanan liang berlebihan pada kedalaman yang berbeza. Sampel tanah yang diperolehi dikelaskan sebagai KELODAK berkeplastikan sangat tinggi (MV) berdasarkan British Soil Classification System (BSCS) dan kelodak elastik (MH) mengikut Unified Soil Clasification System (USCS). Ujian ricih ram telah dijalankan pada kedalaman 600mm, 750mm dan 900mm. Kadar terikan berubah dari 6,9,12,15,18,21 sehingga 24 %/min. Hasil kajian menunjukkan bahawa kebanyakan kekuatan ricih taktersalir dalam kedalaman yang tetap adalah lebih kurang sama dan nilai ini meningkat bersama dengan kedalaman tanah. Tekanan liang berlebihan dilesapkan dengan pantas pada awal penembusan ram dalam tanah. Keadaan ini mengambil masa selama 6 jam bagi tanah kedalaman 600mm dan 3 jam bagi tanah kedalaman 750mm dan 900mm untuk mencapai nilai kemuncak sebelum nilai tersebut menurun dan menjadi stabil. Selain itu, tekanan liang berlebihan disebabkan sisipan dan putaran menjadi kurang dengan kadar terikan yang semakin meningkat. Sebahagian besar daripada perbezaan nilai antara tekanan liang berlebihan disebabkan sisipan ram dan putaran dan tekanan liang berlebihan disebabkan sisipan ram pada kadar terikan yang berbeza adalah dikatakan agak kecil. Di samping itu, keputusan kajian juga menunjukkan bahawa kekuatan ricih taktersalir tanah meningkat dengan pemutaran ram sebelum nilai tersebut mencapai puncak, di mana nilai maksimum untuk kekuatan ricih taktersalir tercapai sebelum nilainya menjadi stabil. Pada masa yang sama, tekanan liang berlebihan meningkat dengan masa dan putaran, bermula dari 0 sehingga 180 darjah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNOTATIONS

°/ min	-	Degree per minute
%	-	Percentage
$\geq$	-	Equal or more than
$\leq$	-	Equal or less than
°C	-	Degree Celsius
°	-	Degree (in rotation)
Δu	-	Excess pore pressure
σ	-	Vertical stress
α	-	Vane size conversion factor
a	-	Radius of sphere of influence
a_v	-	Coefficient of compressibility
c_c	-	Compression index
c_g	-	Coefficient of gradation
cm	-	Centimetre
c_u	-	Uniformity coefficient
c_v	-	Coefficient of consolidation
D	-	Diameter of vane
e	-	Void ratio
g	-	Gram
g/L	-	Gram per litre
G_s	-	Specific gravity
H	-	Height of vane
h_o	-	Datum of water in manometer tube
Δh	-	Head loss in vane test
$h_{container}$	-	Height of the specimen container
H_{dr}	-	Average longest drainage path during consolidation
hr	-	Hour
i_B	-	Taper angle at vane base

i_T	-	Taper angle at vane top
k	-	Hydraulic conductivity/ Permeability
kg	-	Kilogram
kN/m^3	-	Kilo newton per cubic metre
kPa	-	Kilopascal
L_D	-	Length of oven-dried specimen
L_O	-	Original length of specimen
M	-	Peak torque
m/s	-	Metre per seconds
Mg/m^3	-	Megagram per cubic metre
min	-	Minute
ml	-	millilitre
mm	-	Millimetre
m_v	-	Coefficient of volume compressibility
ρ_w	-	Water density
p_s	-	Particle density
$r_{container}$	-	Radius of the specimen container
sec	-	Second
S_t	-	Soil sensitivity
s_u	-	Undrained shear strength
t	-	time
t_{90}	-	Time taken to reach 90 % average degree of consolidation.
t_f	-	Time to failure
$\delta\Delta u$	-	Difference between excess pore pressure due to insertion and excess pore pressure due to insertion and rotation
Δu	-	Excess pore pressure
Δu_i	-	Excess pore pressure due to insertion
$\Delta u_{i(4th\ minute)}$	-	Excess pore pressure due to insertion at 4th minute.
Δu_{ir}	-	Excess pore pressure due to insertion and rotation
w	-	Moisture content
ω	-	Strain rate

μm	-	Micrometre
γ_{sat}	-	Bulk unit weight
γ_w	-	Unit weight of water
ϑ	-	Degree of rotation
σ'	-	Vertical stress

LIST OF ABBREVIATIONS

AASHTO	-	American Assocaition of State Highway and Transportation Officials
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CPTU	-	Piezocone Penetration test
E	-	East
LL	-	Liquid limit
MH	-	Elastic silt
MV	-	Silt with very high plasticity
N	-	North
PI	-	Plasticity index
PL	-	Plastic limit
SL	-	Shrinkage limit
UNIMAS	-	Universiti Malaysia Sarawak
UPVC	-	Universal Polyvinyl Chloride
USCS	-	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In general, geotechnical engineering practice is focusing on the issues related to the bearing capacity and stability of soil for example, slope under heavy structure where pile design foundations and base supporting system have to provide the required strength and stability. Hence, the main parameter to be considered is the shear strength of the soil. Furthermore, construction on soft soil deposit poses more challenge since it is always starts with the determination of shear strength of in-situ soil deposit. The in-situ undrained shear strength is very crucial because the in-situ shear strength is difficult to be performed due to sample recovery profile (difficult to obtain without disturbance).

Generally, the typical tests used to determine the undrained shear strength of undisturbed soils are the unconfined compression test, unconsolidated undrained triaxial compression or vane shear test. Vane shear test is most practically used to assess the in situ undrained shear strength, s_u of the soft and stiff soils, include the clay, silt and peat soil up to 200 kPa due to its simplicity and quick outcome (Schnaid, 2009). However, this test is not recommended for cohesionless soil as partial drainage is not expected in undrained shear strength in vane test.

Basically, the vane shear test is carried out by forcing the vane into the ground to the particular depth and manually turning the vane rod from the vane handle located at te upper end until the soil achieve its failure mode to measure the peak torque applied. The peak torque applied to the soil is converted into undrained shear strength, s_u using the conventional interpretation. In certain cases where the further investigation is required, the vane is rotated instantly at minimum 5 to 10 revolutions to fully remould the soil after peak torque is recorded, in order to determine the residual shear strength and sensitivity of the soil. The analysis of residual shear strength is similar to the computation of undrained shear strength, s_u where torque recorded after the soil is remoulded, is used. From that, ASTM recommended that the strain rate, ω of 0.1 °/s should be applied to conduct the in-situ vane shear test, with the allowable variation of 0.05 to 0.2 °/s.

The ideal relationship between the time to failure, t_f with respect to the torque applied and excess pore pressure change had been proposed by Blight (1968), whereby the torque and excess pore pressure will increase linearly until the stage in which the failure mode is reached, after that the value will be kept constant over the failure time. For this study where the soil is kept to be undrained all the time, the excess pore pressure, Δu is assumed to be kept constant over certain time unless the drainage is allowed to happen, whereby the excess pore pressure, Δu will drop after the failure time, t_f. Besides, the study conducted by Torstensson (1977) had shown that the undrained shear strength, s_u decrease with the reduction of strain rate, ω with the proof that the strain rate with approximately 0.01 °/min produce higher 30 – 40 % undrained shear strength as compared to the standard strain rate of 6 °/min. Thus, it is believed that the undrained shear strength, s_u is expected to increase with the increment of the strain rate, ω .

The strain rate can be explained in different terminology according to the way of strain measurement. Jade LeCocq firstly defined the term "strain rate" in the year 1867 as "the rate at which strain occurs. It is the time rate of change of strain" (Davidson, 2015). In this case, whereby the terminology is based on vane shear test, the strain rate is interchangeable with ''vane rotation rate, shear rate and angular displacement rate'' as adopted by other researchers. Thus, the strain rate in this study is defined as the rate of change of degree of rotation and expressed in the unit of degree per time. The strain in the soil occurs when the shearing effect is applied.

The rate of strain influences the result of vane shear test in such the way that change of undrained shear strength can be observed, as confirmed by Kenney & Landva (1965). Vicat & Collin's studies (as cited in Sathialingam & Kutter, 1989) were the earliest to confirm the effect of strain rate of vane shear test on the undrained shear strength of cohesive soil in year 1833 and year 1846. Richards (1988) mentioned that the undrained shear strength of the vane shear test should consider the stress from the vane insertion, rotation and anisotropy from soft soils. The undrained shear strength is measured with assumption of the existence of pore water pressure within the fully saturated soil. Mitchelle (1962) summarized her findings by hypothesizing that the pore water pressure of particular fully saturated soil mostly results from mechanical effects, ie. the insertion and turning effect during vane test, osmotic or known as ion concentration-related pressure, water adsorptive pressure and hydrostatic pressure. The pore water pressure, expressed in geotechnical terms, is defined as the pressure exerted by pore water (water occupies the void) which exists between the grains of fully saturated soil. As emphasized by Richardson & Whitman (1963), the strength of soil varies with the response of pore water pressure. Consequently, Terzaghi's study (as cited in Mitchelle, 1962) stated that the pore water pressure exists in between the soil particles affect the inter-particle effective stress. Hence, total stress is expressed as the combination effect of effective stress and the stress of pore water. Since the condition of the soil in this study is assumed to be fully saturated under undrained condition, whereby the air void is negligible, hence the pore pressure will be used throughout this paper instead of pore water pressure.

This study focus on the results obtained from a series of vane shear tests on saturated disturbed cohesive soil and investigating on the response of pore pressure and the undrained shear strength corresponding to the angular displacement rate or strain rate. The laboratory experimental tests are conducted at different depth to observe the trend of the pore pressure change and measured torque.

1.2 Problem Statement

Formerly, the in-situ vane shear test is commonly used to measure the shear strength of cohesive soils due to the fact these soils are impermeable soils which impedes any significant passing of water for 2 to 15 minutes in typical vane shear test, as mentioned by Blight (1968). Thus, the in situ vane shear test is appropriate to determine the undrained shear strength of clay.

However, drainage is possible to occur for measurement in silty soil, since the permeability of silty soil is higher than clays (Blight, 1968). In the situation whereby the